



Performance and emissions of a diesel engine fueled by biodiesel-diesel blends with recycled expanded polystyrene and fuel stabilizing additive

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ABSTRACT

Increasingly strict emission regulations along with man-made global warming has peaked interest in clean burning diesel engines. This study investigates performance and emissions of a diesel engine fueled by biodiesel-diesel blends with recycled expanded polystyrene (EPS) and fuel stabilizing additive acetone. A HATZ 2-cylinder direct injection (DI) diesel engine was used for this investigation and the engine was tested at three different engine speeds: low (1000 rpm), medium (2100 rpm) and high (3000 rpm). Three load conditions: low ($\approx 25\%$), medium ($\approx 50\%$), and high (full load) are tested. Brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) are determined as the performance parameters of the engine. Emission analysis was conducted for oxides of nitrogen (NO_x), smoke opacity, and carbon monoxide (CO). Performance and emission results of different blends of EPS-dissolved biodiesel with or without stabilizing additive acetone are compared with that of diesel. Investigation results demonstrate that EPS contributed in increasing heating values of EPS-dissolved biodiesel. Acetone as a stabilizing additive lowered the viscosity and cloud point of the blends. In the drawback side, EPS increased viscosity, and acetone reduced the heating value of the blends. In general, EPS-dissolved biodiesel with or without acetone produced lower smoke, CO and NO_x.

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1. Introduction

Regulation of renewable content in fuel is an effective legislative tool to control emissions. National governments have started to implement policies and research on the potential of renewable content in conventional diesel fuels. India's biofuel policy was set to increase biodiesel and bioethanol to 20% blended with diesel by 2017 [1]. China, which produces 5 million tons of waste cooking oil annually has started to implement regulations on the recycling of waste cooking oil [2]. In Canada Bill C-33, the Canadian Environmental Protection Act mandated 5% renewable content in gasoline and 2% renewable content in diesel by 2012 [3]. Canola is the main oil producing crop in Canada due to high production efficiency in short growing seasons [4]. Overall renewable fuel production worldwide has grown; specifically, biodiesel output has increased to 14.7 billion litres in the last decade. Push for renewable fuels and the ability to run in unmodified diesel engines has made biodiesel a

promising alternative fuel [5]. Additionally biodiesel feedstock includes over 350 oil-producing crops and numerous other potential sources for production [6].

Cheikh et al. [7] tested waste oil canola biodiesel-diesel blends on a light-duty single cylinder diesel engine. Blends were found to decrease HC, CO, and particulate matter (PM), while slightly increasing NO_x for all load conditions. Biodiesel was found to increase in-cylinder pressure, decrease ignition delay, and increase BSFC. Tomic et al. [8] tested Canola biodiesel blends on agricultural tractor engines. Biodiesel blends were found to decrease power, increase BSFC, and increase BTE. Emissions of CO and carbon dioxide (CO₂) were reduced, and NO_x emissions were increased when using biodiesel blends. Aybek et al. [9], also tested canola biodiesel blends on an agricultural tractor to determine ideal blend for performance. At 2100 rpm B20 was found to be the ideal biodiesel blend to use in the agricultural tractor engine. Labeckas and Slavinskas [10], tested canola biodiesel in a four cylinder direct injection diesel engine. Biodiesel blends were found to increase BSFC at all blends. NO_x emissions increased with increasing biodiesel content and CO emissions decreased with increased biodiesel content in blends. HC emissions were found to be low for all fuels.

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Nomenclature

°C	degree Celsius
BSEC	Brake specific energy consumption
BTE	Brake thermal efficiency
CI	Compression ignition
CO	Carbon monoxide
CO ₂	Carbon dioxide
DEE	Diethyl ether
DI	Direct injection
EPS	Expanded polystyrene
HC	Hydrocarbons
NO	Nitric oxide
NO ₂	Nitrogen dioxide
NO _x	Oxides of nitrogen
PM	Particulate matter
RPM	Revolutions per minute

Ozsezen et al. [11] tested waste palm biodiesel and canola biodiesel in a six cylinder DI diesel engine. Engine torque decreased, BSFC increased, and ignition delay decreased for both biodiesel blends. HC, CO, and smoke opacity decreased while NO_x and CO₂ emissions increased for both fuel blends.

Previous research conducted in the engine laboratory at Lakehead University includes [12–17], all of which include emissions from canola oil biodiesel. In Ref. [12], Roy et al. examined biodiesel produced from used and pure canola oil. Biodiesel blends from both feedstocks were found to reduce CO, and HC emissions; however, NO_x was found to increase with biodiesel content. BSFC decreased when using waste oil as a feedstock when compared to pure canola oil biodiesel. Roy et al. [13] examined canola oil biodiesel and kerosene biodiesel blends. NO_x emissions were found to increase with biodiesel content and decrease with kerosene content. In Ref. [14], canola oil biodiesel blends were tested at various load conditions. At low load conditions biodiesel blends were effective in reducing CO and HC emissions while significantly increasing NO_x emissions. At medium to high load conditions, a lower increase in NO_x emissions was obtained from the low load condition. Two recent articles on emissions from a modern heavy-duty diesel engine focused on additives and idling emissions [15,16]. Roy et al. [16], tested effect of additives ethanol and diethyl ether (DEE) on idle emissions for the heavy-duty engine fueled with canola biodiesel blends. Blends with ethanol and DEE were found to be effective in reducing CO emissions and NO_x emissions at idle. Increased biodiesel content was found to reduce HC emissions as well. Roy et al. [16] tested idle emissions of a heavy-duty engine fueled with canola biodiesel blended with cold flow improver Wintron Synergy. Synergy was found to be effective in reducing CO and HC idle emissions, NO_x idle emissions were increased with biodiesel and synergy content. In Ref. [17], the effect of emulsion fuel with different percentages of water concentration was investigated. A significant reduction in NO_x emissions was achieved with the increase in water content in the emulsion at the expense of CO emission increase.

Increases in population and quality of life worldwide has increased the demand for plastic products [18]. Duration of life of these plastics is typically less than one month, therefore mechanical and chemical recycling of these plastics must be considered. Expanded polystyrene is produced by the expansions of a styrene plastic pellet and is used in many single use applications. The raw beads are expanded using steam than aged on a storage floor before being cut into various shapes and sizes. Density of EPS varies with

application, for example insulation EPS has a much higher density. Polystyrene accounts for 22% by weight for all high volume plastics [19]. Since the density of expanded polystyrene is so low transportation from small municipalities or isolated communities is not feasible. This means that often polystyrene ends up in landfills instead of being recycled.

Due to bio solvency properties of biodiesel, polystyrene can be dissolved in biodiesel at room temperature. A study from Iowa state university [20] on the solubility of biodiesel concluded that polystyrene is completely soluble in biodiesel over a wide range of temperatures. Mohammadi et al. [21], tested the solubility of B5 blends with EPS content with and without acetone additive. Biodiesel was found to be a good bio-solvent to dissolve EPS at 50 g/L. Addition of acetone was found to stabilize EPS content. Kuzhiyil and Kong in Ref. [19], found that the feasible limit of fuel pump was 10% polystyrene by weight. Polystyrene was found to be able to reduce NO_x emissions, increase CO emissions and Soot emissions. Studies also examined the effect of exhaust gas recirculation (EGR) which could reduce NO_x emissions but increased CO and soot emissions. Mohammadi et al. [22], studies the performance and emissions of B5 with 25 g, 50 g, and 75 g of dissolved expanded polystyrene. B5EPS50 (50 g EPS dissolved biodiesel 5% and diesel 95%) fuel blend was found to be best fuel with emission reductions in CO, CO₂, NO_x and soot. Small reduction in brake power and increase in brake thermal efficiency were observed at maximum rated power. Aghbashlo et al. [23] also tested B5 with 25 g, 50 g, and 75 g dissolved polystyrene, and once again found B5PS50 the most desirable fuel blend with similar results to the previous study. In another study by Mohammadi et al. [24] acetone was added to biodiesel to improve cold flow properties and stabilize the fuel.

Dissolution of EPS in biodiesel and its use in diesel engine is an emerging area of biodiesel combustion research in diesel engines. However, there are only a very limited number of studies found in the literature. Majority of research on dissolution of EPS in biodiesel has focused on B5 blends with 25 g/L of biodiesel 50 g/L of biodiesel, and 75 g/L of biodiesel of EPS content. Research supports that the best concentration of EPS is 50 g/L of biodiesel [18,20,22]. Performance and emissions have been investigated for only B5 blends. Therefore, EPS content of 50 g/L of biodiesel will be used for all fuel blends and focus will be on increasing biodiesel content in this research. Consensus on fuel stabilizer for EPS content appears less defined, so concentrations of 100 ml acetone/L of biodiesel will be investigated. This work is an addition in the scientific literature with an immense investigation of diesel engine performance and emissions at different loads and speeds with biodiesel-diesel blends up to B50 with EPS and fuel stabilizing additive acetone. This work will fill the gap of research on high biodiesel-diesel blends with EPS.

2. Materials and methods

2.1. Materials

Materials used during the testing and producing of biodiesel included: low sulfur diesel, pure canola oil, methanol, sodium hydroxide pellets, expanded polystyrene and acetone.

2.2. Biodiesel production and fuel properties

The process used for the conversion of food quality canola oil to biodiesel is transesterification. An alcohol is added to a fat or oil to form esters and by-product glycerol [25]. Simplicity and low cost of process allows for widespread use in biodiesel industry. Transesterification was performed on canola oil, with Methanol as the alcohol [26]. Process efficiencies observed averaged 80% Volume

Table 1

Test results of Canola biodiesel per ASTM 6751 [17].

Test name	Test method	ASTM limit	Results
Free glycerin (mass %)	ASTM D6584	Max. 0.020	0.000
Total glycerin (mass %)	ASTM D6584	Max. 0.240	0.112
Flash Point, closed cup (°C)	ASTM D93	Min. 130	169
Water and sediment (vol. %)	ASTM D2709	Max. 0.050	0.000
TAN (mg KOH/g)	ASTM D664	Max. 0.50	0.14
Sim. dist., 50% recovery (°C)	ASTM D2887	N/A	359.8
Cetane index	ASTM D976	N/A	50
	(2 variables formula)		
Copper corrosion, 3 h @ 50 °C (rating)	ASTM D130	Max. 3a	1a

Table 2

Fuel properties of different blends with EPS and acetone.

Fuels	Composition	Viscosity (cSt)	Density (kg/m ³)	Cloud point (°C)	Heating value (kJ/kg)
Diesel	Neat diesel	1.90	820	−40	45573
B5	5% biodiesel in biodiesel-diesel blend	1.92	823	−32	45309
B20	20% biodiesel in biodiesel-diesel blend	2.68	832	−21.2	44518
B50	50% biodiesel in biodiesel-diesel blend	3.20	850	−13.2	42935
B5(EPS)	EPS dissolved in B5	4.15	824	−16.8	45311
B20(EPS)	EPS dissolved in B20	5.36	835	9.2	44524
B50(EPS)	EPS dissolved in B50	7.55	854	15.3	42952
B5(EPS)	EPS dissolved in B5	3.81	820	−20	44495
A100	w/acetone (100 ml/L)				
B20(EPS)	EPS dissolved in B20	4.92	831	8	42972
A100	w/acetone (100 ml/L)				
B50(EPS)	EPS dissolved in B50	6.91	848	10	41556
A100	w/acetone (100 ml/L)				

Collection. Biodiesel produced conformed to ASTM 6751 standards shown in Table 1 [12]. Process was completed on-site in the engine laboratory at Lakehead University.

A third-party laboratory tested fuel according to ASTM D5773 standards. Properties tested include higher heating value, cloud point, viscosity, and density (Table 2).

2.2.1. Polystyrene dissolved in biodiesel

Polystyrene is commonly used for shipping goods, food packaging, and disposable plates/cups. In 2012, household in the United States produced 2,240,000 tons of Polystyrene and only recycled 20,000 [27]. By volume polystyrene can account for up to 22% of plastic waste [28]. If polystyrene can be recycled simply through addition to biodiesel, small municipalities can start to recycle using their diesel fleets. However, the long term effect of the use of EPS dissolved biodiesel in diesel engines needs to be examined. Expanded polystyrene is a polymer composed of 92% carbon and 8% hydrogen by weight [21]. At 50 °C EPS was found to be completely dissolved in less than 20 min. Mohammadi et al. [21] found that when heat treated EPS would completely dissolve, but when fuel blends cooled some EPS will dissolve out. Acetone with a boiling point of 56 °C and latent heat of evaporation of 518 kJ/kg [29] was found to be the best stabilizer by multiple studies [21,22,24]. B5 fuel blends with acetone were found to pass a stability test performed after a two-month period. The maximum quantity that was suggested for EPS dissolution was 50 g/L of biodiesel by both papers in Refs. [20,21]; viscosity above these levels were in unacceptable range for biodiesel blends. Therefore, this study used EPS level at 50 g/L of biodiesel to prepare EPS series fuel blends. In Ref. [24], acetone content was tested from 100 to 250 mL/L of biodiesel.

Table 3

HATZ 2G40 engine specifications.

Engine make and model	Hatz 2G40
Engine type	4-stroke, Air-cooled
Number of cylinders	Two
Bore × Stroke	92 mm × 75 mm
Swept volume	997 cc
Compressions ratio	20.5:1
Fuel injection timing	8BTDC (≤2250 rpm); 10BTDC (≥2300 rpm)
Fuel injection pressure	26 MPa
Continuous max. rated power	13.7 kW @ 3000 rpm

However, acetone content above 100 mL/L of biodiesel did not show any significant improvement in cloud point for pure biodiesel. Furthermore, due to low calorific value of acetone (28,548 kJ/kg), the fuel quality of the acetone-added blends in terms of heat content deteriorates significantly. Therefore, the inclusion rate of acetone is kept minimum at 100 mL/L of biodiesel in this study to prepare EPS series fuel blends with acetone.

2.3. Engine under study

An air-cooled, 2-cylinder, 4-stroke light duty (HATZ 2G40) diesel engine with a direct fuel injection system was used, and its specifications are summarized in Table 3. A schematic diagram for the diesel engine is outlined in Fig. 1 [17]. The engine was mounted on an engine test bed and exhaust was vented outside through the roof of the engine room. Exhaust valves for emissions testing were installed on the exhaust system. The engine was fitted with a water brake dynamometer and a servo controller was installed on the water load release to control engine load. Data acquisition system was attached to a laptop computer to take real time data of tests.

2.3.1. Engine test procedure

The light-duty engine was tested at three speed conditions of 1000, 2100 and 3000 rpm under low load, medium load, and high load at each engine speed. Before any data was taken, the engine ran for 15 min with specified fuels, engine speed and load to allow for emission levels and exhaust temperature to stabilize. Engine Power, torque, rpm, and exhaust gas temperature were measured using a data acquisition board. The data acquisition system was connected via USB port to a laptop computer. Data was recorded and analyzed in Dyno Max 2010 software. Engine load condition was also recorded and controlled with the data system, via a servo controller connected to the load control valve. The engine lab is kept at 20 °C year-round.

2.4. Exhaust emissions and temperature measurement

During installation of exhaust system, aluminum exhaust pipes were punched so that exhaust lines could be connected to three gas

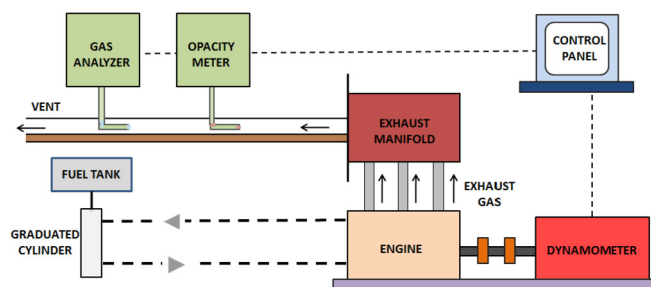


Fig. 1. Schematic diagram of the diesel engine [17].

Table 4
Specifications of the emission measurement devices [17].

Measurement devices and method of detection	Species	Measured unit	Range	Resolution	Accuracy
Nova Gas 7466K:					
Electro Chemical/Infrared detector	CO	%	0–10%	0.10%	±1%
Infrared Detector	CO ₂	%	0–20%	0.10%	±1%
Electro Chemical	NO	ppm	0–2000 ppm	1 ppm	±2%
Electro Chemical	NO ₂	ppm	0–800 ppm	1 ppm	±2%
Electro Chemical	O ₂	%	0–25%	0.10%	±1%
Dwyer 1205A:					
Electro Chemical	CO	ppm	0–2000	1 ppm	±5%
ExTech EA10:					
	Temp.	0.1 °C	–200 °C to 1360 °C	0.1 °C	±0.3%
SMART 1500:					
	Opacity	%	0–100%	0.10%	±0.5%
	Soot density	mg/m ³	0–10 mg/m ³	0.00001	±0.5%

measurement systems. A thermocouple was inserted into the exhaust gas system at the same time. CO, CO₂, NO, NO₂, O₂ and opacity were tested using a Dwyer handheld CO meter, a NOVA gas analyzer and a SMART opacity meter. NO and NO₂ sensors both have a resolution of 1 ppm. The CO₂ sensor has a resolution of 0.1 mol% of gas analyzed. Opacity was measured using a SMART 1500 with an opacity range of 0–100% and a soot density range of 0–10 mg/m³. The specifications of the emission measurement devices with range, resolution and accuracy are shown in Table 4 [17]. At each test condition, data of different performance parameters and emissions were taken three times, and average of that is used to plot performance and emission graphs.

3. Results and discussions

3.1. Engine performance

3.1.1. BSEC

Fig. 2 (a, b, c) illustrates the BSEC for the EPS series at 1000, 2100 and 3000 rpm, respectively. It is seen that BSEC decreases

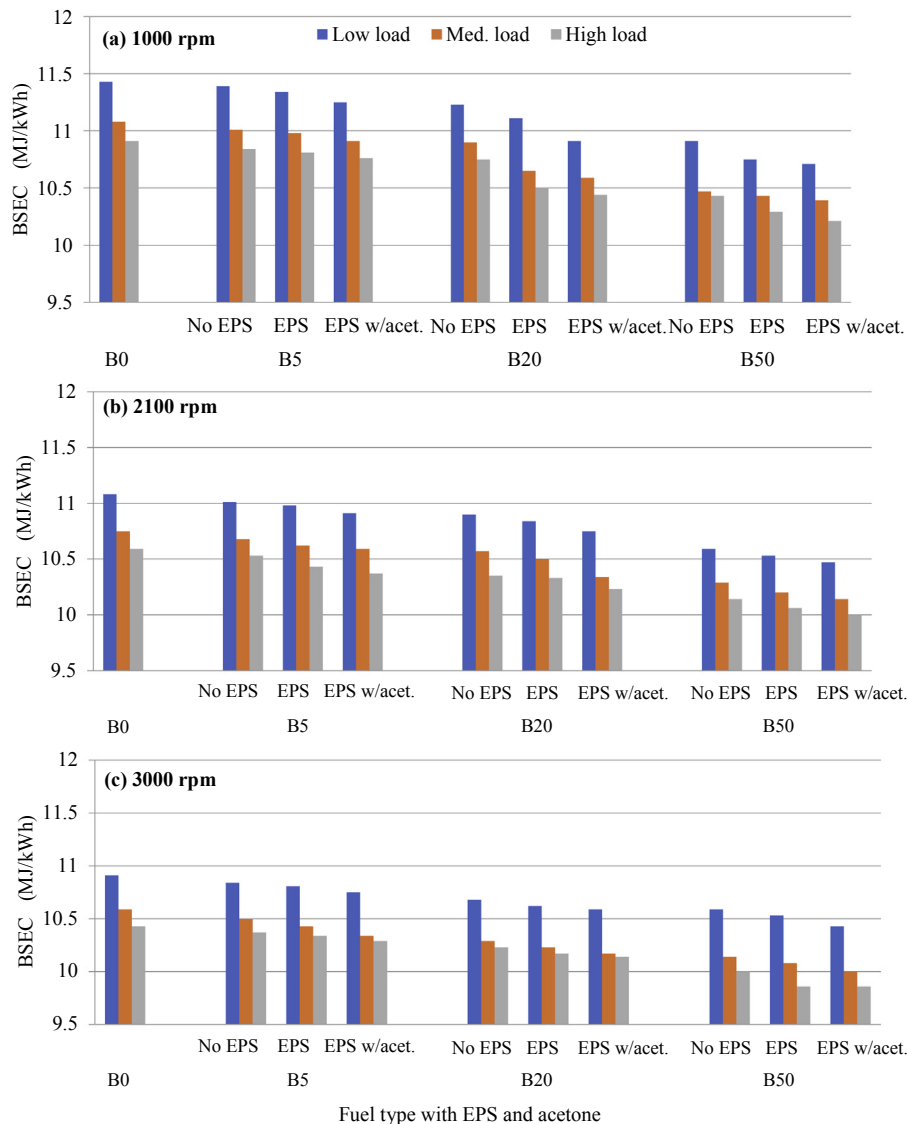


Fig. 2. BSEC of different fuel blends at (a) 1000 rpm, (b) 2100 rpm and (c) 3000 rpm.

with increasing load. This is because at high engine load the combustion is improved due to higher in-cylinder temperature. At all rpm conditions, biodiesel with EPS and acetone shows gradual decrease in BSEC, and the higher the biodiesel percentage, the lower the BSEC values. B50 with EPS and acetone achieved the lowest BSEC, which is approximately 5–6% lower on average than the BSEC of petroleum diesel. Therefore, higher biodiesel percentage with EPS and acetone had better BSEC than diesel at all engine conditions, which was proved to be a promising fuel blend in this diesel engine.

3.1.2. BTE

Fig. 3 (a, b, c) represents the BTE at 1000, 2100 and 3000 rpm of biodiesel blends, biodiesel blends with EPS content, and EPS-dissolved biodiesel blends with acetone. BTE is increased with load, biodiesel content, EPS, and acetone at all engine speeds. At 1000 rpm, diesel has 31.5–33% of BTE from low to high load conditions, whereas, EPS-dissolved B20 and EPS and acetone added biodiesel blends for B50 showed BTE of 33–35.25%. Similar trends in BTE (but a slight increase in efficiency) for different fuels are obtained at 2100 rpm, and the highest BTE obtained for EPS and acetone added B50 is 36%.

Maximum BTE obtained in this work is 36.5% for EPS and acetone added B50 blends. All blends with biodiesel, EPS and acetone performed better than neat diesel at all load conditions. This may be due to higher oxygen content of biodiesel and better volatility of acetone, which improved combustion as well as BTE of this engine.

3.2. Emissions

3.2.1. NO_x emissions from fuel blends

Fig. 4 (a, b, c) represents the average NO_x emissions for 1000, 2100 and 3000 rpm at all load conditions. As expected the increase in biodiesel content caused increases in NO_x emissions, because of oxygen content in biodiesel (Fig. 4 (a)). B50 at 1000 rpm emits 6–17% more NO_x than diesel at various loads. However, EPS-dissolved B50 with or without acetone emits 21–30% less NO_x than diesel. In-cylinder temperature has a significant effect on NO_x emission and usually, high the in-cylinder temperature, the higher the NO_x emission is, and vice versa. Higher viscosity of EPS-dissolved B50 blend (Table 2) may have caused improper atomization and worse mixing at low rpm condition, and a result of lower in-cylinder temperature than diesel

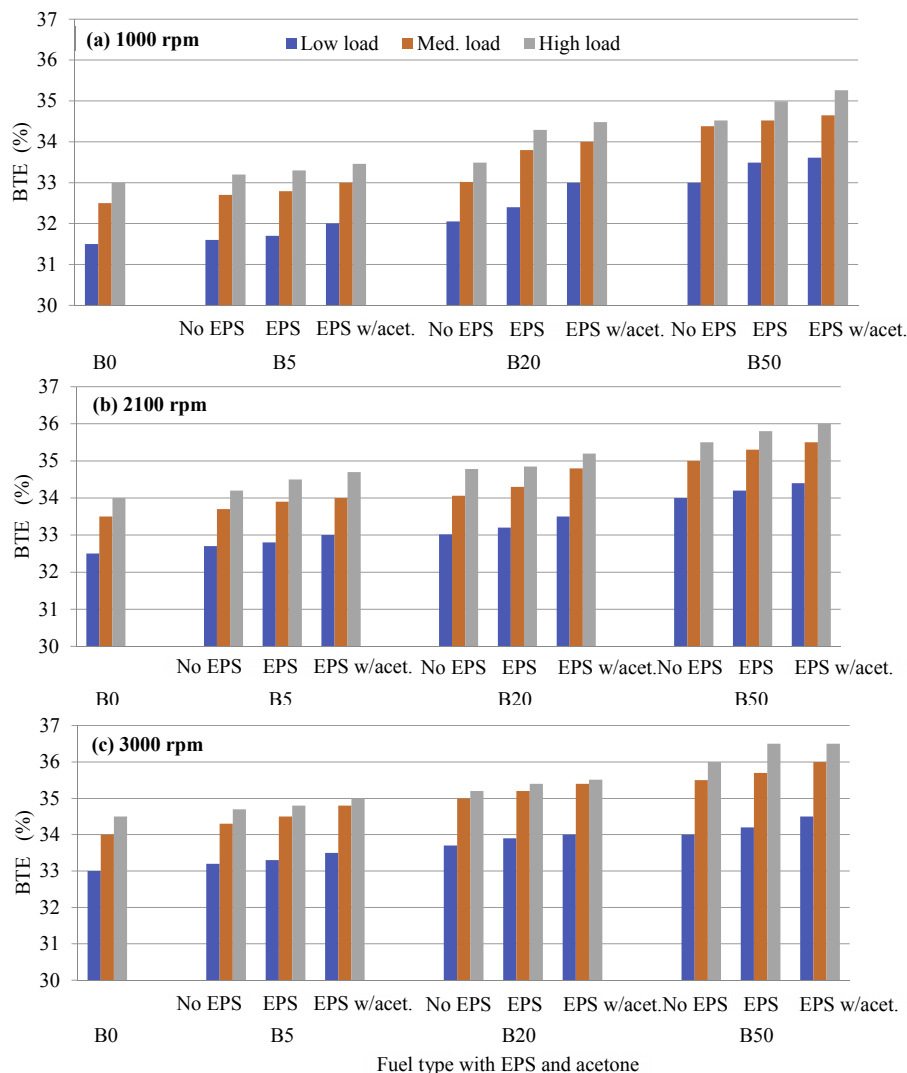


Fig. 3. BTE of different fuel blends at (a) 1000 rpm, (b) 2100 rpm and (c) 3000 rpm.

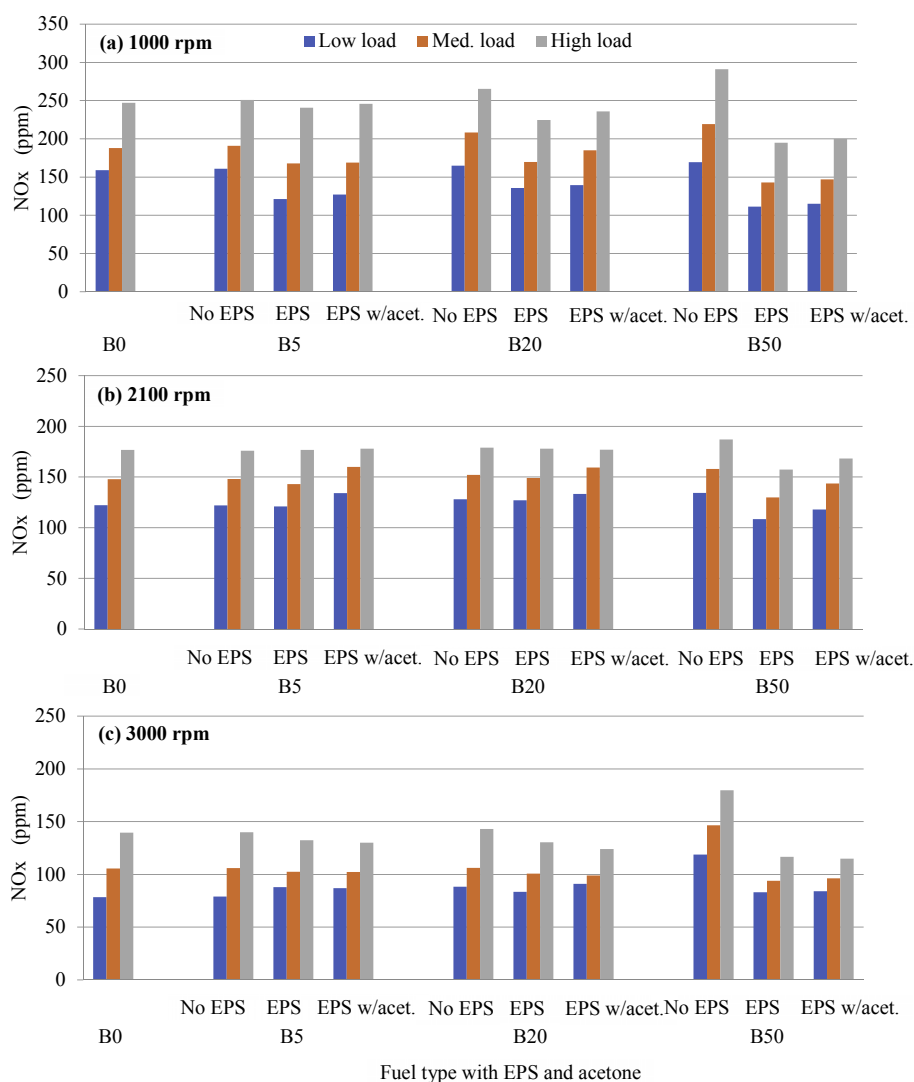


Fig. 4. NO_x emissions of different fuel blends at (a) 1000 rpm, (b) 2100 rpm and (c) 3000 rpm.

combustion. On the other hand, acetone added B50 blend has significantly lower heating value (Table 2) than diesel, which may have caused lower in-cylinder temperature. Fig. 4 (b) demonstrates the average NO_x emissions at 2100 rpm, which is peak torque condition. Once again biodiesel content increase NO_x emissions due to higher oxygen content, and B50 at 2100 rpm emits 6–10% more NO_x than diesel at various loads. Once again EPS-dissolved B50 has the minimum NO_x emission. Acetone added biodiesel blends also showed lower NO_x emissions than diesel, because of lower heating value of the blends, especially, acetone added B50 blend. Fig. 4 (c) illustrates the average NO_x emissions for the 3000 rpm condition at all loads. Here B50 showed 30–50% NO_x increased at different loads than that of diesel. EPS-dissolved B50 with or without acetone once again maintained the lowest NO_x emissions. From Fig. 4, it is noticed that NO_x increased with loads, due to increased fuel consumption and in-cylinder temperature. As the NO_x is measured in ppm (vol %), higher engine speed has lower ppm, because of higher exhaust gas flow rate at high speed conditions.

3.2.2. Smoke emissions from fuel blends

Fig. 5 (a, b, c) shows the smoke opacity for different fuel

blends at 1000, 2100 and 3000 rpm, respectively. Biodiesel, typically decrease particulate matter (PM) emission with increased biodiesel content [30,31]. This has been attributed to oxygen content in fuel helping for a more complete combustion. In the case of the light-duty engine it appears that the smoke opacity does not have significant change with increased biodiesel content for 1000 and 2100 rpm, however, reduced smoke opacity is obtained with higher biodiesel content at 3000 rpm. Other prominent trends included that increased engine speed and load decreased smoke opacity. This may be due to increase in-cylinder temperatures at high-load and high-speed engine running conditions. At 1000 rpm, there is no significant change in smoke opacity up to B20 blends, however, EPS-dissolved B50 blends with or without acetone generate a significant increase in smoke emissions. Higher viscosity of EPS-dissolved B50 blends and lower heating value of acetone added blends make lower in-cylinder temperatures, which may have deteriorated smoke emissions. At 2100 rpm, the smoke opacity trend is pretty similar to that with 1000 rpm, but with lower magnitude, and acetone added B20 showed the minimum smoke emissions. Here EPS-dissolved B50 blends showed only a small smoke increase than diesel. The smoke opacity

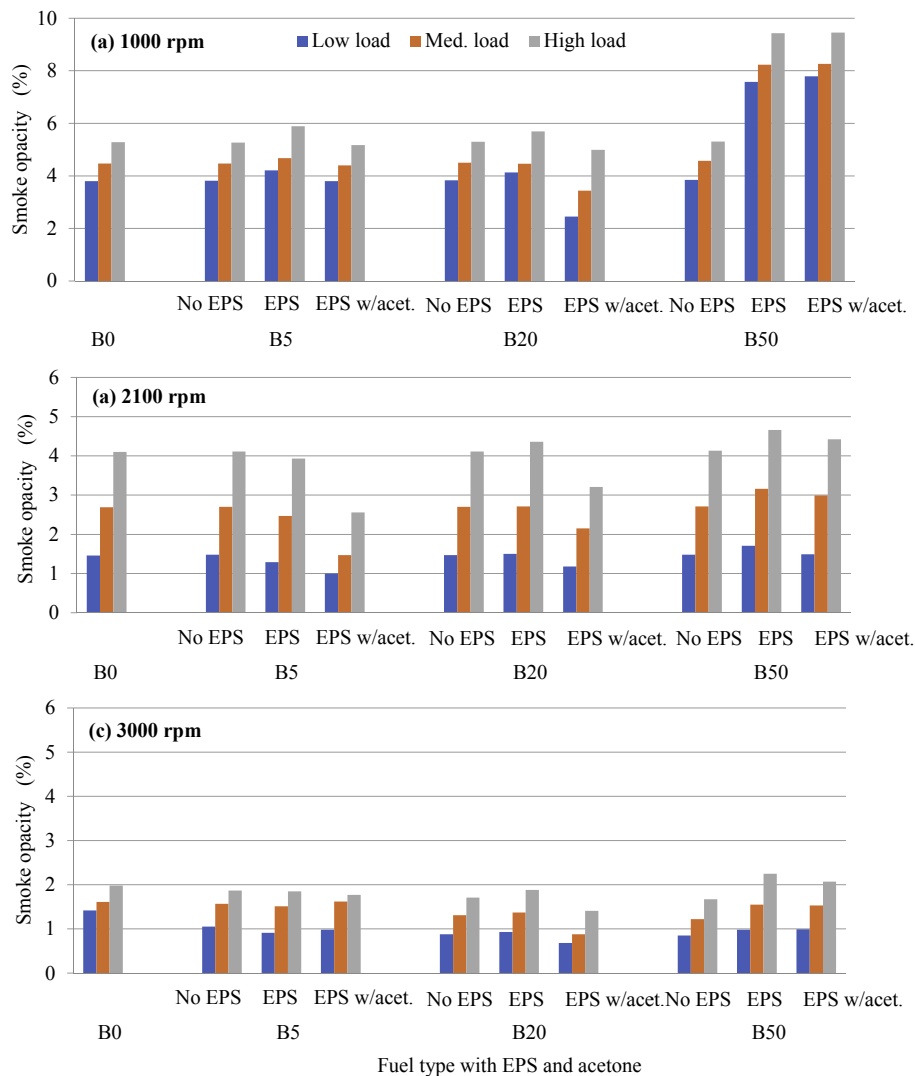


Fig. 5. Smoke opacity of different fuel blends at (a) 1000 rpm, (b) 2100 rpm and (c) 3000 rpm.

further reduced at 3000 rpm with highest magnitude average about only 1.7%, and acetone added B20 has the least smoke again. It seems that higher volatility of acetone helps to reduce smoke opacity at 2100 and 3000 rpm engine running conditions for acetone added blends.

3.2.3. CO emissions from fuel blends

Fig. 6 (a, b, c) shows average CO emissions for different fuel blends at 1000, 2100 and 3000 rpm under various loads. Typically, biodiesel content is expected to lower CO emissions due to oxygen content in biodiesel, which is true for all loading conditions at 1000 rpm. Average CO reduction with B50 compared to diesel is approximately 8%. Acetone added B20 and B50 showed the minimum CO emissions at 1000 rpm. This could be due to high volatility of acetone that helps better mixing of fuel with air. At 2100 rpm, overall CO emissions were reduced in magnitude than 1000 rpm and average CO reduction with B50 compared to diesel is approximately 30%. High in-cylinder temperature at higher engine speed reduced more CO. Acetone added B20 and B50 showed the minimum CO emissions, and the CO reduction is about 58% than diesel, which is the maximum reduction in all

conditions. When the engine speed increases from 2100 to 3000 rpm, overall CO reduction at 3000 rpm has less decrease than at 2100 rpm. Although acetone added B20 and B50 again shows minimum CO emissions, its CO emission becomes approximately 28% lower than diesel. This lesser CO reduction at 3000 rpm, when the in-cylinder temperature is the highest suggests that highly volatile acetone (for acetone added blends) may have caused overleaning producing higher unburned hydrocarbon, which is converted to CO at a later stage of combustion. The general trend in CO emissions of this research is that higher load reduced CO emissions due to high in-cylinder temperature. Higher biodiesel content in the blends produced lower CO emissions, which is attributed to the oxygen content in biodiesel. EPS-dissolved B20 and B50 with or without acetone showed the lowest CO emissions, which could be due to a combination of favorable effects of those blends due to higher heating value of EPS, higher volatility of acetone and oxygen content of biodiesel. However, the negative effect of overleaning at the highest in-cylinder temperature condition (3000 rpm) dominates over the positive effect of higher volatility of acetone and causes higher CO emissions than that of 2100 rpm.

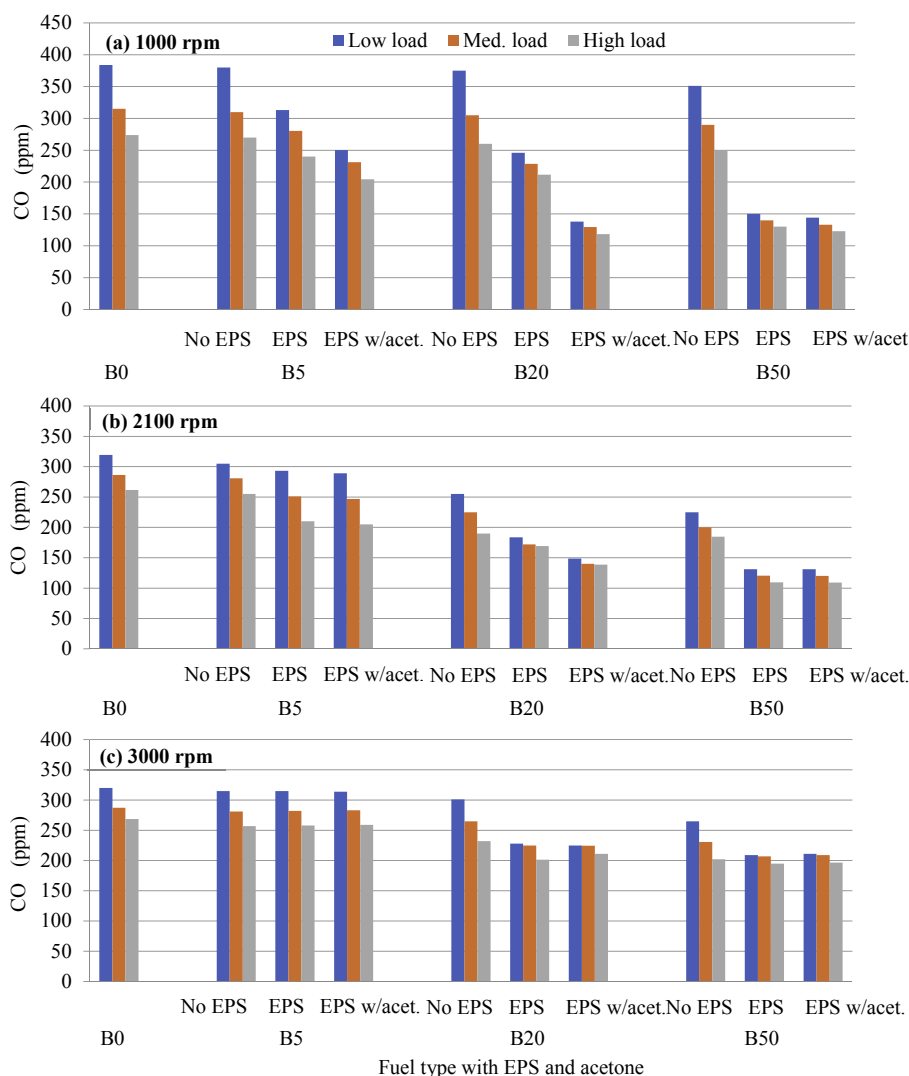


Fig. 6. CO emissions of different fuel blends at (a) 1000 rpm, (b) 2100 rpm and (c) 3000 rpm.

4. Conclusions

A modern light-duty diesel engine was fueled by biodiesel-diesel blends with dissolved expanded polystyrene, and fuel stabilizer additive acetone. Three fuel series tested were biodiesel-diesel blends, biodiesel-diesel blends with dissolved EPS, and biodiesel-diesel blends with dissolved EPS and acetone. Conclusions from the results are summarised below.

- 1) B5(EPS) and B20(EPS) showed similar or better BSFC than diesel at all engine conditions and proved to be a promising fuel blend in a small diesel engine.
- 2) All blends with biodiesel, EPS and acetone showed higher BTE than diesel at all load conditions, and EPS and acetone added B50 blends showed the highest BTE.
- 3) Generally, biodiesel-diesel blend series increased NO_x emissions from neat diesel levels, however, EPS-dissolved B50 with or without acetone emitted much lower NO_x than diesel. Therefore, EPS with or without acetone is found as NO_x reducers when added with higher biodiesel blends.
- 4) There is a general concept that biodiesel reduces smoke than diesel. This has only happened at the highest speed condition (3000 rpm) of this research work. The other two speeds (low and moderate) generated similar smokes for biodiesel-diesel

series and diesel. EPS-dissolved biodiesel up to B20 with or without acetone showed pretty much similar smoke emissions compared to diesel. At low engine speed, EPS-dissolved B50 blends have the highest smoke emissions.

- 5) All EPS-dissolved B20 and B50 blends with or without acetone produced lower CO emissions than diesel. The lowest average CO emission reading obtained was 120 ppm for B50 with acetone, which is 58% lower than its base fuel.

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